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6. AUTHOR(S)
PROFESSOR KHITROVA

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
UNIVERSITY OF ARIZONA
SPONSORED PROJECTS SERVICES
PO BOX 3308
TUCSON AZ 85722

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
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13. ABSTRACT *(Maximum 200 words)*

John Prineas was the student supported by this AASERT. In our Progress Reports of July 31, 1998 and June 30, 1999, he described his research on radiatively coupled quantum wells with narrow exciton linewidths (' ~ <O.6 meV) and with periods in the vicinity of half the wavelength of light in the semiconducting material (X012n 830 nm/(2x3.6) 115 nm). [1-8] John won a Dean's Fellowship, so he no longer needed AASERT support for his salary. Soon after he received an unusual invitation to spend several months at Bell Laboratories in the laboratory of Jagdeep Shah. AASERT funds were used for his travel and living expenses, making possible this industrial experience and leading to very significant results described in the next section and published in Physical Review Letters.

John studied the resonance Rayleigh scattering of disordered periodic semiconductor multiple quantum-well structures experimentally with Jagdeep Shah at Bell Labs. Polaritonic effects were found to dominate the secondary emission dynamics due to the coexistence of several radiant modes with different radiative decay times. They give rise to polarization beating between modes and determine rise and decay times of the resonance Rayleigh scattered signals. These results have been published in Physical Review Letters [9].

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Controlling Spontaneous Emission in Semiconductor Microcavities

FINAL REPORT
February 24, 2001

Galina Khitrova, PhD
Optical Sciences Center
University of Arizona
Tucson, Arizona

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AASERT Final Report

John Prineas was the student supported by this AASERT. In our Progress Reports of July 31, 1998 and June 30, 1999, he described his research on radiatively coupled quantum wells with narrow exciton linewidths ($\approx$0.6 meV) and with periods in the vicinity of half the wavelength of light in the semiconducting material ($\lambda_0/2n \approx 830$ nm/(2×3.6) $\approx$ 115 nm). [1-8] John won a Dean's Fellowship, so he no longer needed AASERT support for his salary. Soon after he received an unusual invitation to spend several months at Bell Laboratories in the laboratory of Jagdeep Shah. AASERT funds were used for his travel and living expenses, making possible this industrial experience and leading to very significant results described in the next section and published in Physical Review Letters. John also participated in the resolution of a long standing puzzle, a third peak seen in the nonlinear transmission of a normal-mode-coupling microcavity, as described in the third section. John is now working with Dr. Juergen Kuhl at the Max Planck Institute in Stuttgart, Germany, supported by a Humboldt Postdoctoral Fellowship.

Dominance of Radiative Coupling Over Disorder in Resonance Rayleigh Scattering in Semiconductor Multiple-Quantum-Well Structures

John studied the resonance Rayleigh scattering of disordered periodic semiconductor multiple quantum-well structures experimentally with Jagdeep Shah at Bell Labs. Polaritonic effects were found to dominate the secondary emission dynamics due to the coexistence of several radiant modes with different radiative decay times. They give rise to polarization beating between modes and determine rise and decay times of the resonance Rayleigh scattered signals. These results have been published in Physical Review Letters [9]. A detailed paper on the theory of resonance Rayleigh scattering in the presence of disorder and radiative coupling has been submitted to Physical Review B [10]. Talks were given on this subject [11,12], and it was included in "Optics in 2000" [13].

One of the most intriguing aspects of light emitted in directions different from the excitaton and reflected beams is the interplay of structural disorder, Coulomb interaction, and radiative coupling effects in multiple quantum well structures. A quantum well (QW) is known to be affected by two important symmetry breaking mechanisms. The translational symmetry in the direction perpendicular to the QW is broken, relaxing conservation of momentum, and allowing the excitons to couple to a continuum of photon modes in the forward and backward direction. In MQW structures, such a radiative decay channel couples the N QW's by light, giving rise to N exciton-polariton eigenmodes, each characterized by its individual eigenenergy and radiative width, i.e., its radiative decay. Disorder due to interface roughness or alloy fluctuations breaks the in-plane translational invariance, relaxing in-plane conservation of momentum, and allowing coherent emission in nonspecular directions.

The length scale and amplitude of the disorder potential is supposed to determine the spectrum and time dynamics of resonance Rayleigh scattering (RRS) in a specific sample. However, radiative coupling – being a general, intrinisic property of a periodic MQW – alters the emission environment considerably; emission can be suppressed or enhanced depending on the periodicity, the spacing between two adjacent QW's. Many of the past RRS studies have been performed on periodic MQW structures, and yet in all cases polaritonic effects were ignored or ruled out.

We studied the interplay of structural disorder and radiative coupling effects in the very low intensity regime. We showed both experimentally and theoretically that the RRS carries the imprint of the emission environment rather than information about disorder when the radiative coupling strength exceeds the disorder scattering rate. Because the strength of the coupling of a mode to the light field varies with periodicity, only a few modes have sufficient oscillator strength to be observed simultaneously at a given periodicity. Consequently, they appear as distinct peaks in the coherent Rayleigh scattering spectrum and as polarization beating in time. The characteristic time of both the rise and decay of the RRS signal can be dominated by the radiative width of the polaritonic mode rather than by the inhomogeneous linewidth of the particular QWs.

The experiments were performed using a spectral interferometric technique. 130 fs pulses at a repetition rate of 82 MHz from a mode locked Ti:Sapphire laser were focused to a 50 μm diameter spot on samples held at 5 K in an open flow Helium cryostat. The exciting pulse was incident on the sample at an angle of about 10 degrees, and secondary emission was collected in an approximately 10 degree half width cone about the specularly reflected pulse. Single speckles were isolated by placing an iris in the path of the secondary emission. The speckles were combined with a split off reference pulse from the Ti:Sapphire in the plane of a pinhole spatial filter. The result was then sent to a 2/3 m spectrometer with a 110 μeV bandpass, and imaged onto a liquid nitrogen cooled CCD with a 60 meV spectral window. From the interferogram the phase and amplitude of the coherent part was extracted, i.e. the RRS contribution to the total secondary emission was measured.

The experimental and theoretical RRS from the 100 MQW clearly showed that polaritonic effects can dominate over the disorder in controlling the rise, decay, and beating of the RRS. While these data were collected in a MQW sample with large N, we also have observed pronounced splitting and beating of eigenmodes in an N = 30 MQW sample, showing polaritonic effects dominate there as well.

Third-Transmission-Peak Mystery Solved

John wrote in the Progress Reports that nonlinear measurements for an excitation resonant with the normal-mode peaks in a semiconductor microcavity show a very intriguing effect. A third peak in transmission (or a 3rd dip in reflection) shows up between the two normal-mode peaks. It appears both in nonlinear fs single beam experiments and in ps-pump-probe experiments [14]. Microscopic calculations (done by

M. Kira) based on a quantized light description show that quantum fluctuations give rise to intraband coherences if simultaneously an interband polarization and a pump-induced occupation of electron and hole states is present. These quantum correlations couple back to the interband polarization via guided modes. They contribute to the phase space filling and consequently to the macroscopic polarization. Measurements on an oxide-aperture nanocavity showed no third peak confirming the important role of the guided modes in this effect. Additional measurements and calculations were performed to clarify the dependence of the 3rd peak on the energetic position of the pump pulse and its spectral shape. The results were published in Physical Review Letters [15].

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